Design of a New Low-Consumption Fluxgate Sensor

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***Abstract*—This paper presents a new current sensor for DC and low frequency AC measurement, which is based on closed-loop fluxgate technology. The designed sensor consists of a special core-winding structure to decrease the noise coupled to feedback winding and possibly coupled to the primary winding. A prototype of the sensor was designed. Test results show that the proposed sensor can measure currents up to 30A, and has an accuracy of 0.4％ and a remarkable resolution.**

***Index Terms*— current sensor, cross winding structure, fluxgate principle, toroidal magnetic cores**

I. INTRODUCTION

In many industrial applications, the measurement of electrical currents is increasingly required. The measurement of the electrical current can be made by means of different concepts or technologies. The main current sensing methods include shunt resistors, current transformers, Hall-effect transducers, Rogowski coils, magnetoresistors, and fluxgate current sensors. A more detailed description and comprehensive review of these methods can be found in [1].

Various structures of fluxgate sensor and test methods have been reported to improve the property of the sensor: a fluxgate current sensor with three cores having high current measurement and low consumption [1], an orthogonal fluxgate current sensor with improved fluxgate equivalent magnetic noise and simplified fluxgate output processing [2], a method to reduce magnetic noise [3], a method with pulse feedback to improve accuracy [4], a double core fluxgate current sensor with low interference [5].

This paper proposes a new fluxgate current sensor, which consists of a special core-winding structure. The proposed sensor has higher accuracy and a remarkable resolution.

II. STRUCTURE AND PRINCIPLE OF THE DESIGNED SENSOR

Traditionally, fluxgate current sensors consist of a primary winding, an excitation winding, a feedback winding and a magnetic core. Excitation winding is excited by square voltage which makes the core to be in oversaturated and unsaturated state, alternatively. But transformer effects also exist between windings of a sensor, that is, the magnetic field produced by excitation winding can be coupled to feedback winding and possibly coupled to the primary winding [1].

To reduce the noise level, a new current sensor is proposed in this paper as shown in Fig. 1. The designed current sensor consists of two cores (C_1 and C_2) and a special core-winding structure. The magnetic flux generated by exciting current (I_e) is Φ_{e1} in core C_1, and Φ_{e2} in core C_2. With the proposed structure, the magnetic flux Φ_{e1} in core C_1, and Φ_{e2} in core C_2 should have same value but opposite direction. Thus, the total magnetic flux coupled to the feedback winding and primary winding should be zero and no transformer effects exist between the excitation winding and the feedback winding, or between the excitation winding and the primary winding.

Additionally, the proposed fluxgate current sensors have the following advantages: the resistance and the inductance of the excitation coil can be decreased, which means lower power loss of the sensor and/ or lower excitation voltage; external interference can be decreased.

The operating principle of the proposed sensor, based on the fluxgate principle, is shown in Fig. 1. The exciting source used in the sensor is an ac voltage with a square waveform. The voltage across the sampling resister R_s is the input to the hysteresis comparator, which generates a square voltage waveform. Then the output of the hysteresis comparator feeds to the exciting winding W_e. When the detected current I_p is zero and possible stray magnetic fields are neglected due to the shielding effect of core C_2, there is no external magnetic flux in the core C_1. In this case, the exciting winding has a symmetric current waveform. The magnetic field induced by the detected current I_p leads the exciting current waveform to be asymmetric in duration. The asymmetric current waveform flows into the integrator and results in a nonzero output signal which is the input to the H-Bridge Drive. The current I_f from the H-Bridge Drive flows through the feedback winding to the measurement resistor R_m. The magnetic flux induced by the feedback current tries to cancel out the magnetic flux induced by the detected current and tends to obtain a zero-flux state. The current flowing through the measurement resistor R_m is directly proportional to the detected current.

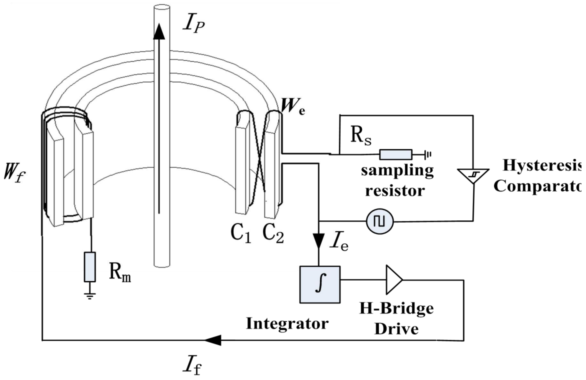
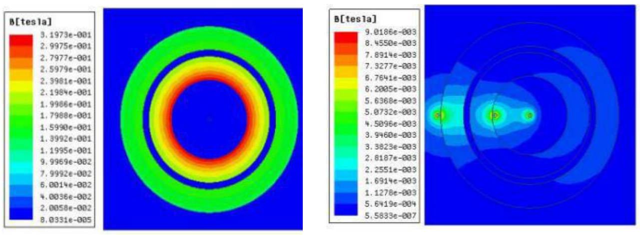


Fig. 1. Principle of the proposed sensor

III. SIMULATION ANALYSIS AND TEST RESULTS

A prototype of the sensor was designed based on analytical and simulation results. The magnetic core made of nanocrystalline soft magnetic material is from the company VAC. Simulation and test research had been implemented for the designed sensor.

Finite Element Analysis (FEA) results in Fig. 2 (a) shows that, without feedback compensation winding, the flux through the toroidal magnetic core leads to a non zero-flux state. In contrast, the whole system can reach a dynamic balance state with the feedback compensation winding, as the simulation result shown in Fig. 2 (b), and at that point, the magnetic-flux density is approximately equal to zero in the toroidal magnetic core. In the process of the simulation, the BH curve of nanocrystalline soft magnetic material was used, as shown in Fig.3.



(a) (b)

Fig. 2. Magnetic-flux density distribution (a) without compensation (b) in the dynamic balance state

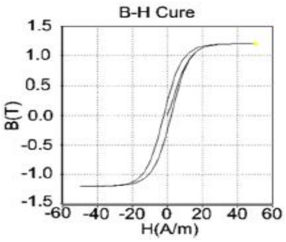
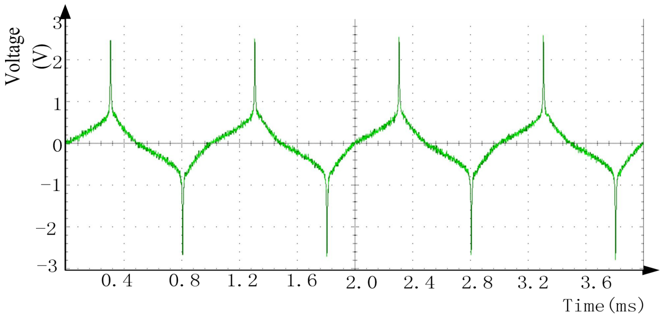
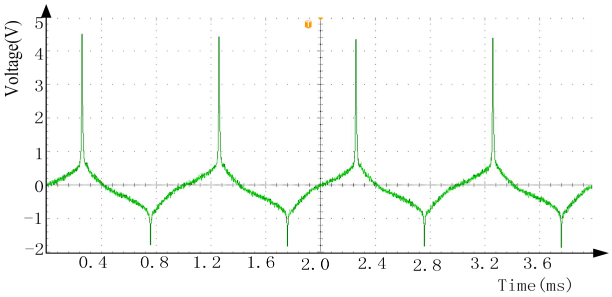


Fig.3 Magnetization curve of nanocrystalline soft magnetic core

In the test process, the exciting winding is excited by square voltage with the frequency of 1 kHz and the amplitude of 12V. When the primary current I_p=0 A, the voltage waveform of the sampling resistor (R_s) is obtained as shown in Fig. 4(a). When the primary current I_p=2A, the voltage waveform of the sampling resistor is obtained as shown in Fig. 4(b). Compared Fig. 4(b) with Fig. 4(a), it shows that the primary current affects the excitation current.



(a)



(b)

Fig. 4 Voltage waveform of the sampling resistor. (a) when I_p=0A. (b) when I_p=2A.

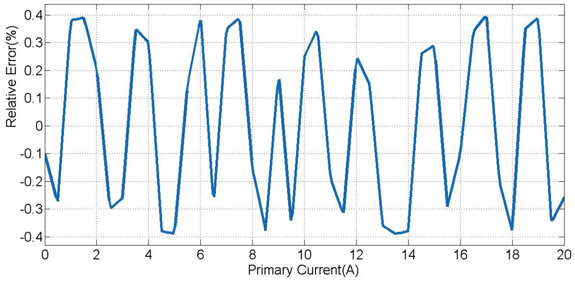


Fig. 5. Relative error of the proposed sensor

The relative error of DC measurement are shown in Fig. 5. A more detailed presentation of the resolution, sensitivity, noise as well as other performance parameters of the proposed current sensor will be introduced in the full manuscripts.

IV. CONCLUSION

The proposed fluxgate current sensor with a special core-winding structur works in a closedloop configuration, which greatly improves the sensitivity and precision of the sensor, and significantly reduces hysteresis effect. The proposed sensor can measure currents up to 30A, and has an accuracy of 0.4%.

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